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Monitoring Vegetation Greenness With Satellite Data

**Robert E. Burgan
Roberta A. Hartford**

AVHRR
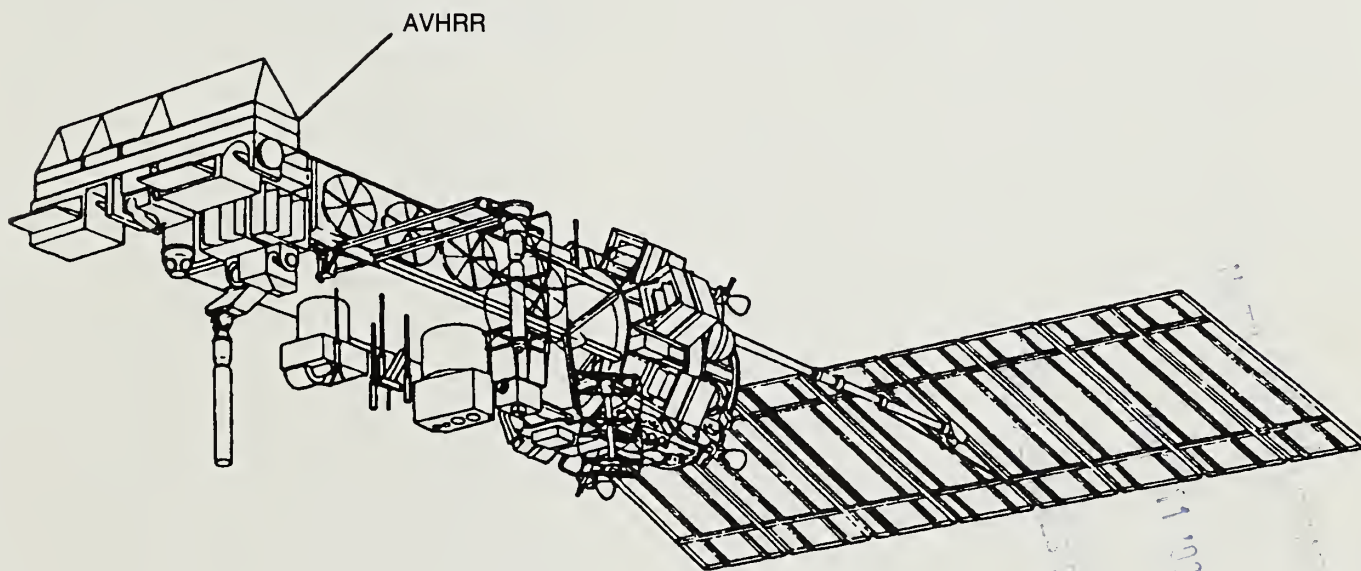
THE AUTHORS

ROBERT E. BURGAN received his bachelor's degree in forest engineering in 1963 and his master's degree in forest fire control in 1966 from the University of Montana. From 1963 to 1969, he served on the timber management staff of the Union and Bear-Sleds Districts, Wallowa-Whitman National Forest. From 1969 to 1975, he was a research forester on the staff of the Institute of Pacific Islands Forestry, Honolulu, HI. From 1975 to 1987, he was at the Intermountain Fire Sciences Laboratory, Missoula, MT, first as a member of the National Fire-Danger Rating Research Work Unit, and then as a research forester in the Fire Behavior Research Work Unit. From 1987 to 1989 he was in Macon, GA, at the Forest Meteorology and Eastern Fire Management Research Work Unit, a part of the Southeastern Forest Experiment Station. In 1989 he returned to the Fire Behavior Research Work Unit in Missoula.

ROBERTA A. HARTFORD began working at the Intermountain Fire Sciences Laboratory in Missoula, MT, in 1968 assisting with research of chemical and physical properties of forest and range fuels. In the early 1970's she taught high school sciences and did seasonal work on the Lolo National Forest in fuel inventory. Since 1976 she has remained at the Fire Lab involved in analysis of fuel and fuel bed properties, smoldering combustion, and fire behavior of laboratory and wildland fires. Recent and current work include studies in the use of satellite remote sensing to assess fire potential in wildland vegetation, collecting fire behavior documentation, and using geographical information system technology to document wildfire growth. Roberta received her undergraduate degree in zoology in 1970 and a master's degree in forestry with soils and fire management emphasis in 1993 from the University of Montana.

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INTRODUCTION

Current assessment of living vegetation condition relies on various methods of manual sampling. While such measurements can be quite accurate, they are difficult to obtain over a broad area, so they fail to portray changes in the pattern of vegetation greenness across the landscape. The technology discussed in this report provides several improvements—it covers large geographic areas, the assessment is updated weekly, it is easily obtained, and it is inexpensive.

The technology needs to be incorporated into an integrated fire danger/behavior system, and that system is currently being developed by the Fire Behavior Research Work Unit of the Intermountain Fire Sciences Laboratory in cooperation with other researchers and fire managers. The proposed system will use new satellite and weather technologies. These technologies and data include improved weather information resulting from the National Weather Service's modernization program, geographic information systems, digital terrain data, and increased reliance on satellite observations of seasonal changes in live vegetation condition.

This report looks at the use of satellite data within the larger fire danger/behavior system. We present it separately at this time to give land managers an opportunity to become familiar with it.

Fire managers need direct observation of vegetation greenness because living vegetation has a strong effect on the propagation and severity of wildland fires. The 1988 revision to the 1978 National Fire Danger Rating System (Burgan 1988) requires ocular estimates of vegetation greenness, but these are difficult to obtain, especially for large areas. Improved observations can be obtained frequently on a continental scale from the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration's (NOAA) polar orbiting weather satellites (Kidwell 1991). The remote sensing community has used AVHRR data to develop a Normalized Difference Vegetation Index (NDVI) (Goward and others 1991; Spanner and others 1990; Tucker 1977; Tucker and Choudhury 1987; Tucker and Sellers 1986). The index is sensitive to the quantity of actively photosynthesizing biomass on the landscape.

While we are not ready to provide live vegetation moisture content assessments, we have used this index to develop two vegetation greenness measures useful to fire managers both as an aid to estimating broad area fire potential and for managing prescribed fires. We also expect these greenness measures to be useful to land managers of other disciplines. For example, watershed managers could obtain basic information on timing and extent of snow cover. Range managers could make weekly observations of vegetation greenness at 1-km resolution. Pest managers find this information useful because insect activity is tied to vegetation flush, which can be observed with this technology. While we won't address the subject in this paper, geographers have used NDVI data to develop a map that portrays vegetation patterns across the United States (Loveland and others 1991). Additional uses are likely to be identified as this technology emerges from the testing phase into more general application by a wider audience.

This report discusses the concepts, interpretation, use, and acquisition of broad-scale vegetation greenness images useful to the land manager. We also provide information on obtaining the necessary software and hardware.

HOW THE IMAGES ARE PRODUCED

The TIROS-N series of polar-orbiting weather satellites from NOAA provide daily global observations of Earth's surface. The data from afternoon satellite overpasses of the United States are received daily at the Earth Resources Observation Systems (EROS) Data Center (EDC) in Sioux Falls, SD.

The spatial resolution of the AVHRR is 1.1 km when the satellite is directly overhead. Thus, a square, 1.1 km on a side, is the ground area represented by each picture element, or pixel. The AVHRR sensor onboard the NOAA afternoon satellite (in 1993, NOAA-11) collects reflectance data in five spectral channels. For each pixel, a numeric value is recorded, representing the amount of light reflected from Earth's surface, in each channel's range. However, channel 1 (red, 0.58 to 0.68 microns) and channel 2 (near-infrared, 0.725 to 1.10

microns) are the most useful for monitoring vegetation and are used to calculate the NDVI.

The NDVI is the difference of near-infrared and visible red reflectance values normalized over total reflectance. That is,

$$NDVI = \frac{\text{Near } IR \text{ (Channel 2)} - \text{Red (Channel 1)}}{\text{Near } IR \text{ (Channel 2)} + \text{Red (Channel 1)}}$$

This equation produces NDVI values in the range of –1.0 to 1.0, where negative values generally represent clouds, snow, water, and other nonvegetated surfaces, and positive values represent vegetated surfaces. The NDVI relates to photosynthetic activity of living plants. The higher the NDVI value, the more "green" the cover type (Deering and others 1975). That is, the NDVI increases as the quantity of green biomass increases.

Cloud-free observations of the land surface are necessary for monitoring vegetation with satellites. The likelihood of a single AVHRR overpass being completely cloud free is minimal. Holben (1986) showed that compositing AVHRR data acquired over several days produces spatially continuous cloud-free imagery over large areas with sufficient temporal resolution to study green vegetation dynamics. The duration of consecutive daily observations is referred to as the compositing period. The compositing process requires each daily overpass to be precisely registered to a common map projection to ensure that each pixel represents the same ground location each day.

The method for determining which portion of each overpass to include in the composite is based on the maximum NDVI decision rule. For each pixel, the highest NDVI value in the compositing period is retained. This reduces the number of cloud-contaminated pixels because cloud and cloud shadow values are generally negative, while clear day observations of vegetated surfaces are positive. The resulting maximum NDVI composite is a near cloud-free image that depicts the maximum vegetative greenness for the compositing period. The EDC has been producing such biweekly NDVI composites of the conterminous United States since 1990 (Eidenshink 1992). In addition, 1989 data have recently been made available by EDC.

Operationally, it is desirable to have a new assessment of the vegetation condition more than once every 2 weeks. Therefore, the biweekly NDVI composite image is updated every week. A new biweekly image is produced each week by dropping the oldest week's data and adding the newest week's data. Figure 1 presents selected biweekly images for 1992. These show the capability of the NDVI to portray seasonal change in vegetation greenness.

An intuitive color palette contains red through tan tones that indicate mostly cured or sparse vegetation.

Yellow and light green indicate moderate quantities of green vegetation, while darker green tones represent more luxuriant vegetation. Bare soil, snow, and clouds are white. Water is blue.

Sample NDVI values are also presented graphically with numbers that range from 0.0 to 0.66; 0.66 is the approximate maximum NDVI value obtained from observing dense, green vegetation of the conterminous United States.

Graphic comparisons of NDVI values show that grass, shrub, and forested pixels trend differently ' (fig. 2A). High NDVI values indicate complete or nearly complete coverage by green vegetation. Low values indicate cured or sparse vegetation.

Differences in timing and extent of greenness within a vegetation type can be observed at specific sites across different years (fig. 2B, C, D). Finally, the NDVI allows observation of differences in the timing of greenup as a function of elevation (fig. 2E).

To interpret the NDVI values for field use, we have devised methods to convert the NDVI data into more easily understandable representations of vegetation greenness. These are called "visual greenness" and "relative greenness."

Visual greenness (VG) indicates how green each pixel is in relation to a standard reference such as a highly green and densely vegetated agricultural field. It is calculated as:

$$VG = ND_o/0.66*100$$

where

ND_o = observed $NDVI$ value for a given 2-week period.

An image is produced that portrays vegetation greenness as you would expect to see it if you were flying over the landscape. In this context, normally dry, sparsely vegetated areas, such as in Nevada, will look cured compared to normally wet, fully vegetated areas such as the coastal forests of Washington and Oregon.

Because the visual greenness images may indicate rather limited changes over time, a second measure of vegetation greenness is useful. Relative greenness (RG) is also a percentage value, but it expresses how green each pixel currently is in relation to the range of greenness observations for that pixel since January 1, 1989. It is calculated as:

$$RG = (ND_o - ND_{mn})/(ND_{mx} - ND_{mn})*100$$

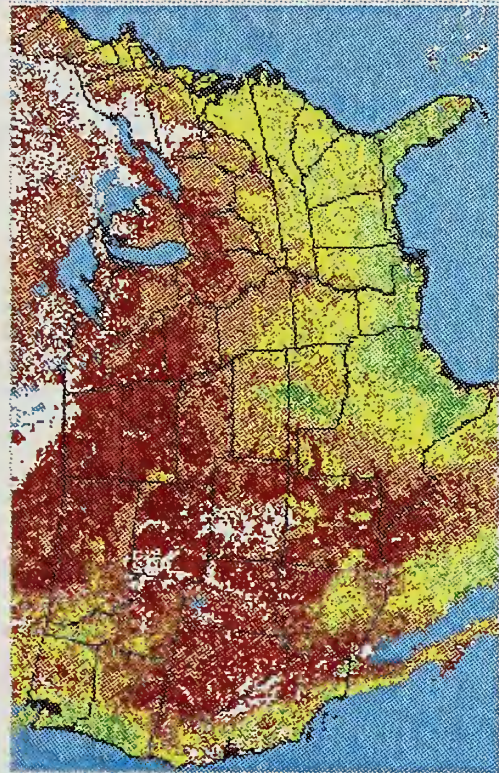where

ND_o = observed NDVI value for a given 2-week period
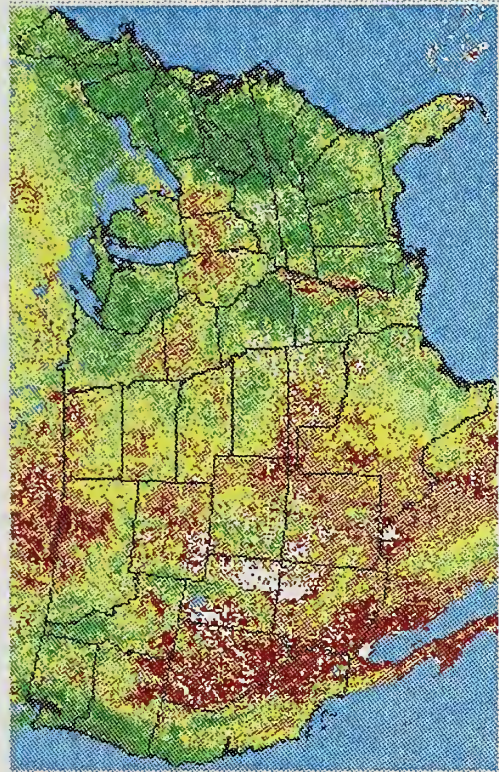ND_{mn} = minimum NDVI value observed historically for that pixel
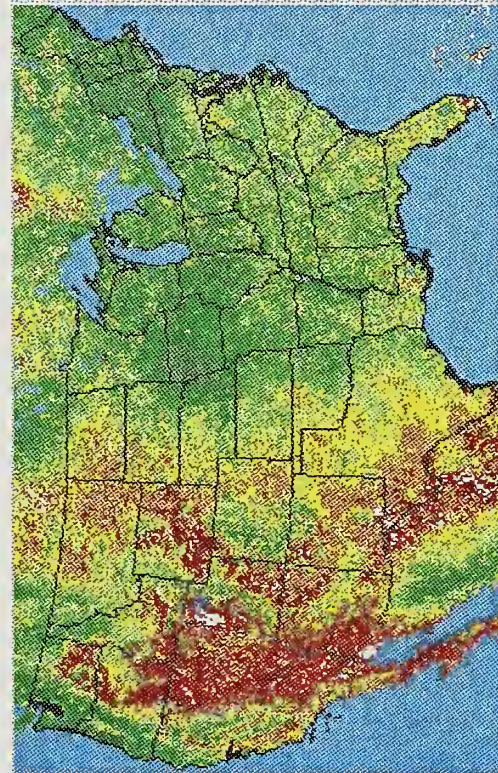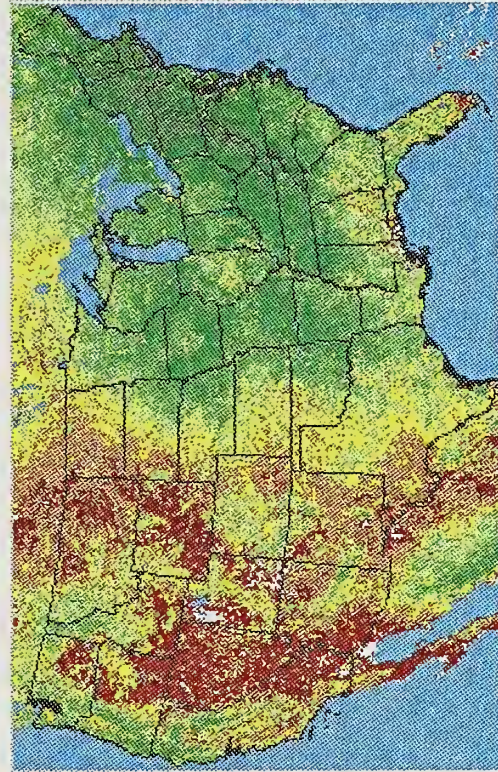ND_{mx} = maximum NDVI value observed historically for that pixel.

RAW NDVI MAPS

March 26, 1992

June 4, 1992

August 27, 1992

October 10, 1992

Figure 1—Selected biweekly NDVI images for the United States illustrate the capability of the NDVI to portray seasonal changes in vegetation greenness.
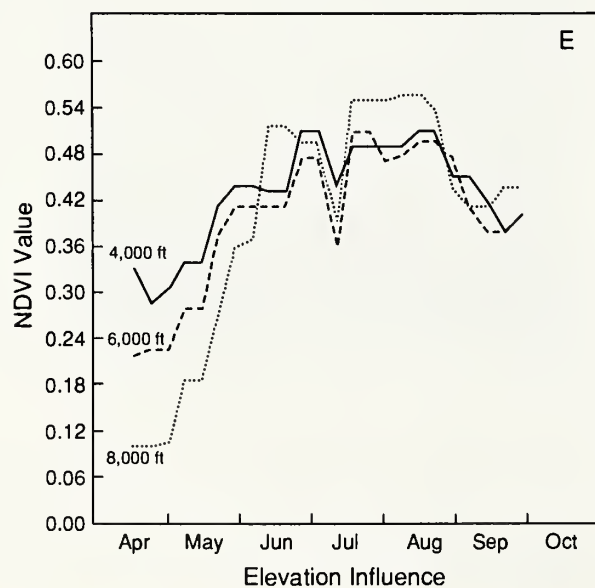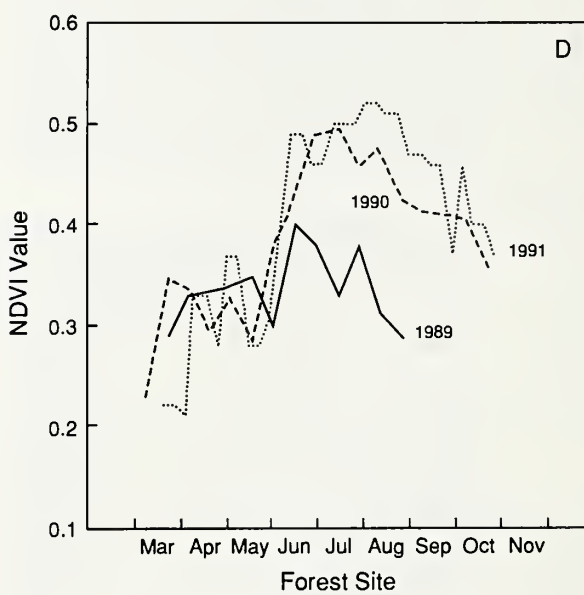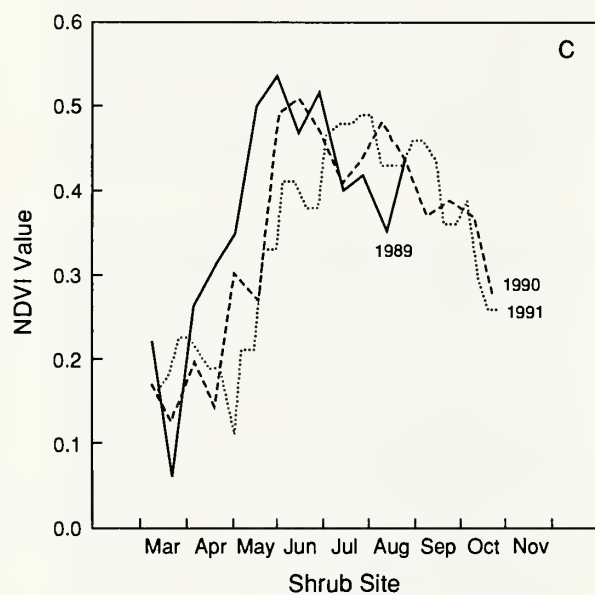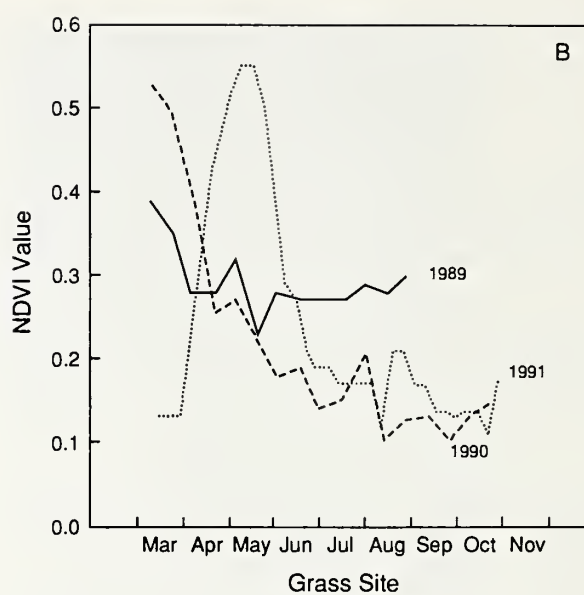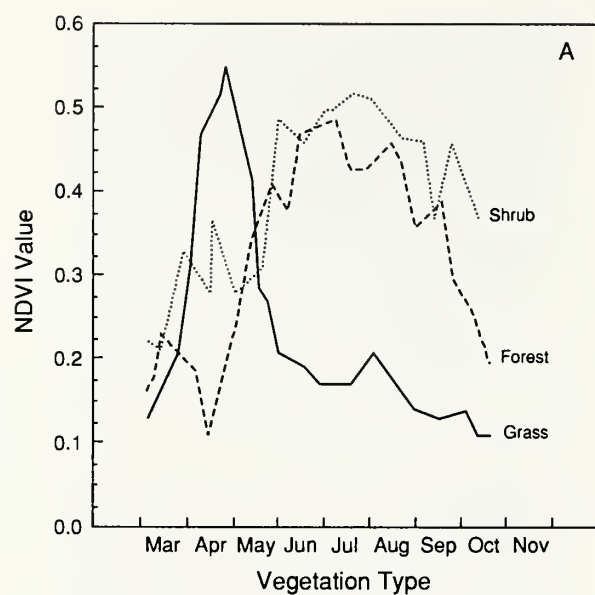
Figure 2—(A) Example Montana forest, Colorado shrub, and California grass sites show differences in seasonal greenness trends. (B,C,D) Annual differences in timing and amount of greenup can be observed within grass, shrub, and forest vegetation at specific individual locations. (E) Elevational differences in the timing and amount of greenness can be observed.

Figure 3 shows the difference between the visual and relative greenness calculations. The left vertical bar, labeled "Raw NDVI Scale," represents the maximum likely range (0.00 to 0.66) of NDVI values that will be encountered in any vegetation type. The next vertical bar to the right, labeled "Visual Greenness Scale," is simply the NDVI range converted to a percentage scale. Assuming a raw NDVI value of 0.25, the visual greenness value would be 38 percent (rounded) because 0.25 is about 38 percent of 0.66, the maximum likely NDVI value. Because visual greenness is calculated strictly as a percentage of the maximum NDVI (0.66), all vegetation types are referenced to a single scale. Therefore, dry land vegetation may never produce an NDVI value much greater than 0.25, so it may never show as being much more than 38 percent green on the visual greenness map. But a wet site would most likely show nearly 100 percent green on this map sometime during the growing season.

The next two vertical bars to the right represent the relative greenness concept. Two examples are given, one labeled "Dry Site" and the other "Wet Site." The dry site NDVI range goes from 0.05 to 0.30 and the wet site ranges from 0.20 to 0.60. While the ranges given here are just examples, actual values have been determined for every square kilometer of the United States from 4 years of historical data, as of December 31, 1992. For the dry site, the assumed NDVI value of 0.25 is at 80 percent of the range between the minimum and maximum (0.05 and 0.30) values recorded historically for that site. That is, relative greenness = (0.25 − 0.05)/(0.30 − 0.05)*100, or 80 percent. This site would appear fairly green on the relative greenness map because it is about 80 percent as green as it has ever been historically. For the wet site, an actual NDVI value of 0.25 is at about 12 percent of the range between its minimum and maximum values (0.20 and 0.60), so its relative greenness = (0.25 − 0.20)/(0.60 − 0.20)*100, or about 12 percent. This site would appear quite dry on the relative greenness map because its NDVI value of 0.25 is still far below the historical maximum of 0.60 for this site. In other words, this site is much less green than its historical maximum.

Historical maximum and minimum NDVI maps for the entire United States are produced by searching all the biweekly NDVI values recorded for the period of record and saving the largest and smallest values observed for each pixel. Pixels affected by clouds and snow are excluded. These NDVI values are then composited into maximum and minimum maps and used with current biweekly NDVI maps to perform the visual and relative greenness calculations (fig. 4). The historical NDVI data base is updated annually.
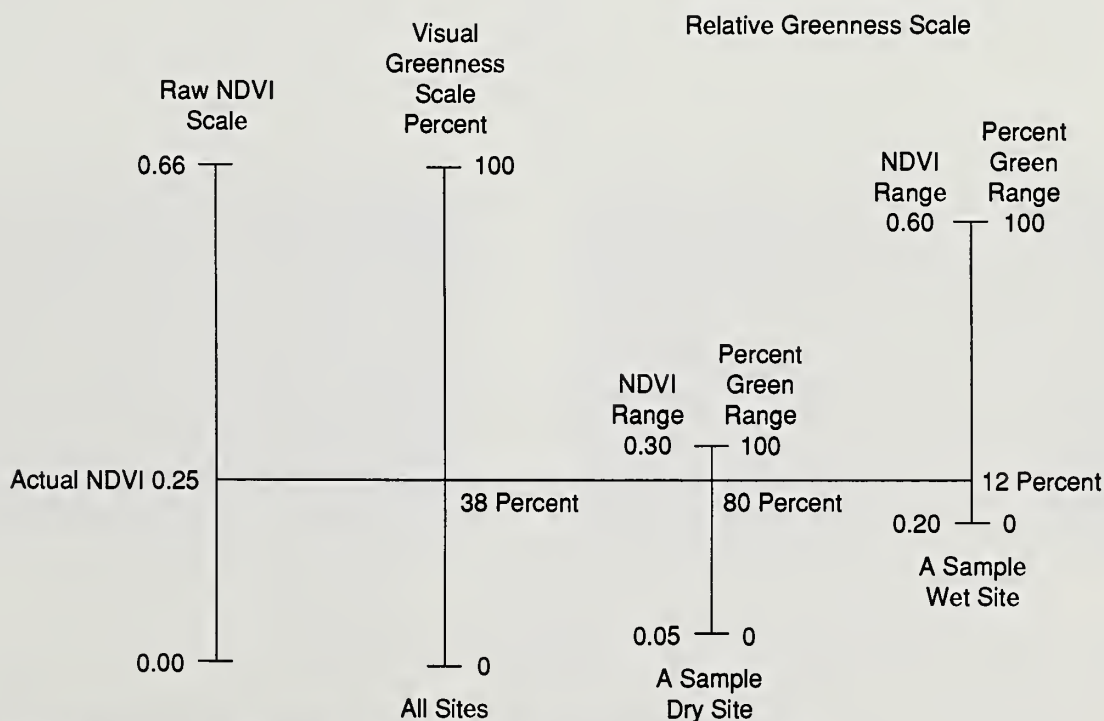

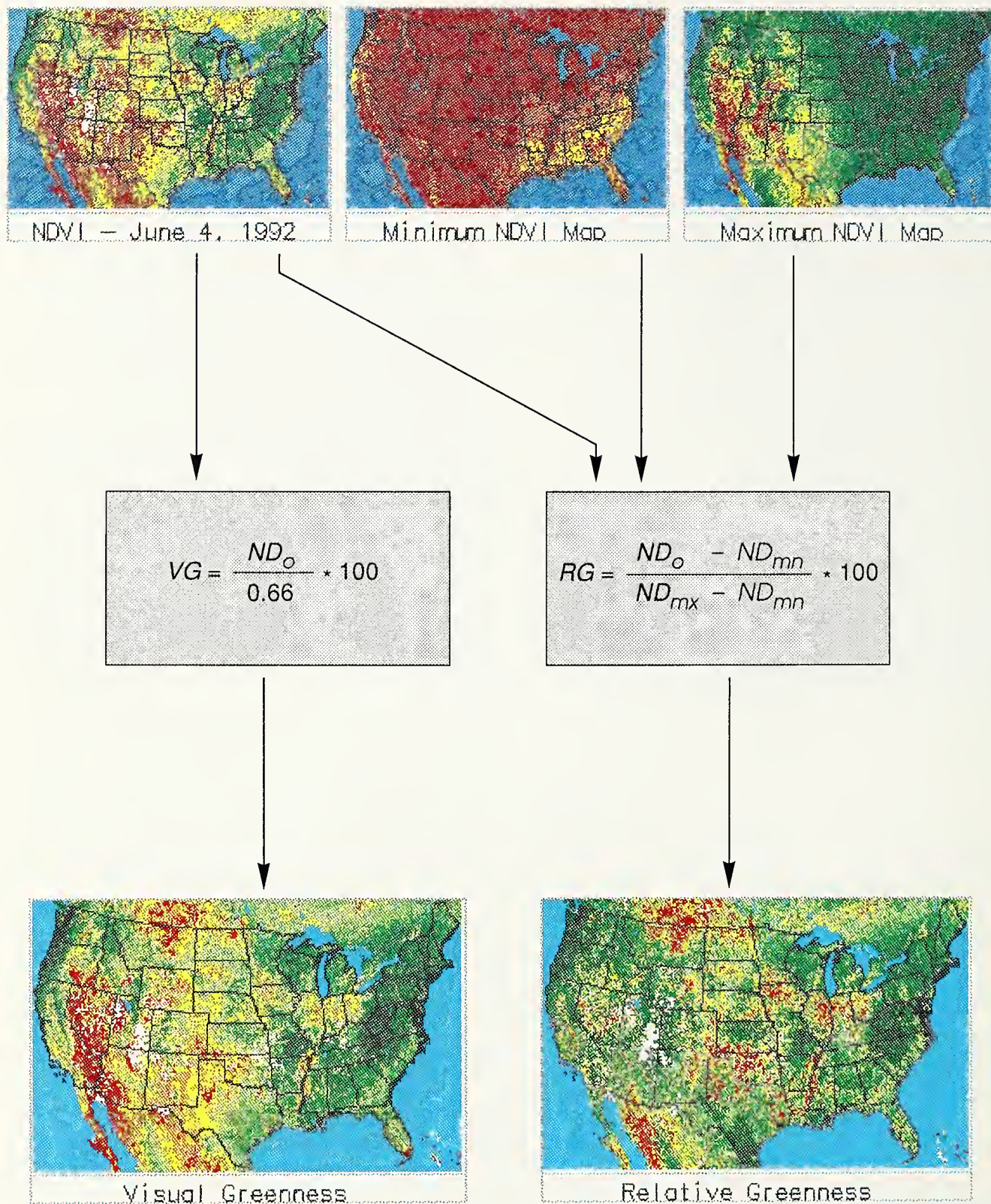**Figure 3**—Any given NDVI value will produce different percentage values of visual and relative greenness.

NDVI — June 4, 1992

Minimum NDVI Map

Maximum NDVI Map

$$VG = \frac{ND_o}{0.66} * 100$$

$$RG = \frac{ND_o - ND_{mn}}{ND_{mx} - ND_{mn}} * 100$$

Visual Greenness

Relative Greenness

Figure 4—Visual and relative greenness maps are produced by processing current and historical NDVI data differently.

INTERPRETATION

Visual and relative greenness maps portray different greenness patterns because each has a different frame of reference. For example, visual greenness maps will normally portray Nevada as having large dry areas. Such a map is intuitive. But for the relative greenness maps, each pixel's reference value is based on its historical behavior. This does not produce a greenness map that looks intuitively correct. Nevada may look only moderately green if you were flying over it in the spring, but if that is as green as it gets, the relative greenness map would show it as fully green. The visual and relative greenness images should be viewed together because each presents different, but valid, information.

Figure 5 illustrates the differences in greenness portrayal that occur. For the image pair dated March 26, 1992, the visual greenness map portrays the Baja California, southern California, and southwestern Arizona area as moderately green to cured. However, the relative greenness map indicates this area is very green. Both maps are providing good information. Because this is a dry environment there is not a lot of green vegetation even in the wet time of the year, so this area does not appear very green in comparison to an agricultural field. This is what the visual greenness map shows. On the other hand, the relative greenness map indicates that this is about as green as it is going to get. This can be verified by looking at this same area in the June, August, and October maps.

The coniferous forests in the Southeastern United States produce the moderate greenness seen on the visual greenness map for March 26, 1992, but red tones on the relative greenness map for that date indicate the intensity of greenness is still far below what can be expected to occur later in the year. The June 4 relative greenness map indicates this is the greenest period depicted by these four dates, although it may well have occurred at some other time not illustrated here. Similar comparisons can be made for other parts of the United States.

Comparison of vegetation greenness between years can also be helpful. Figure 6 shows the difference in vegetation greenness for parts of Washington, Oregon, Idaho, and Montana at the end of May for 1991 compared to 1992. There is a much more extensive snowpack at this time in 1991 (white areas) than in 1992. A sequence of such images for the 2 years indicates that greenup started and ended earlier in 1992 than in 1991 for eastern Washington, northern Idaho, and western Montana. A comparison of the two images also reveals a large area of delayed greenup due to extended dryness in southern Canada and north-central Montana in 1992 compared to 1991.

Rather than just visually comparing maps of the same area for different dates, one can also calculate a difference map by subtracting, pixel by pixel, the percentage green values of one map from the percentage green values of another map, then assigning a color palette. Such maps are useful to highlight and quantify changes in greenness from one time to another. Figure 7 shows a difference map for the western two-thirds of Washington, calculated by subtracting the visual greenness map for May 14, 1992, from the visual greenness map for June 4, 1992. Because the older map was subtracted from the more recent one, those areas that have greened up during this period have positive difference values, while those that lost greenness have negative differences. For example, a pixel having a percentage greenness value of 47 in the map dated June 4 and a value of 39 in the map dated May 14, would have a difference of +8 and be colored light green in the difference map. The legend in figure 7 presents the colors associated with several ranges of positive and negative differences. Note that the area east of the Cascade Range cured between May 14 and June 4, but that western Washington greened up during that time.

A variety of vegetation occurs within each 1-km-square pixel, so the percentage greenness represents an integration of all the vegetation in the pixel. For example, a pixel representing a coniferous forest will have a lower greenness value if the understory is cured than if it is green. There are few cases where crown closure is so tight that understory vegetation does not affect the NDVI response. Seasonal greenness response is directly affected by all the vegetation within the pixel.

Because the maps discussed here portray changes in vegetation greenness over time, it is necessary to look at them routinely as they become available during the year. Much more information can be obtained by comparing changes between maps over time than by simply looking occasionally at individual maps.

APPLICATIONS

Although greenness is presented here in map form, numerical values for specific pixels can be obtained from the underlying data. The image display program identified later in this publication can be used to display greenness histograms for individual pixels over time, or greenness values can be extracted for analysis by other software.

Because greenness data are available for the conterminous United States, they can be used at a variety of management levels, from national to regional to district. The NDVI data file to calculate greenness for the entire United States is large—13 megabytes.
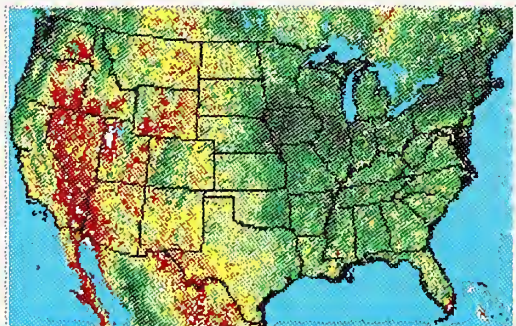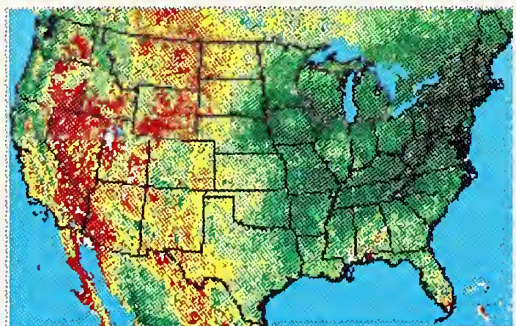
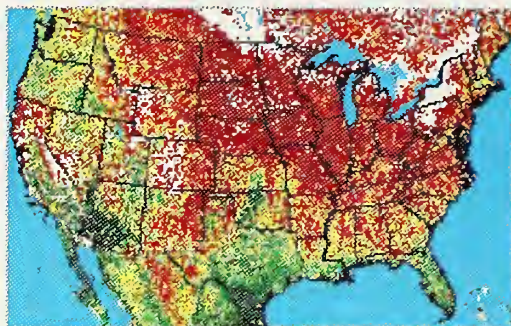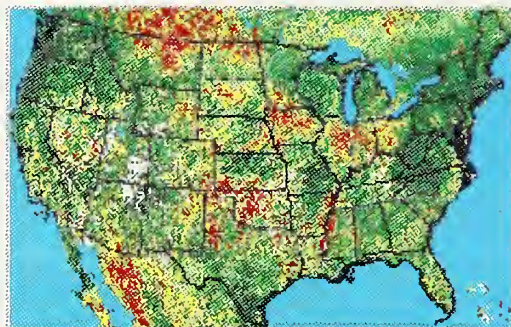**VISUAL GREENNESS**
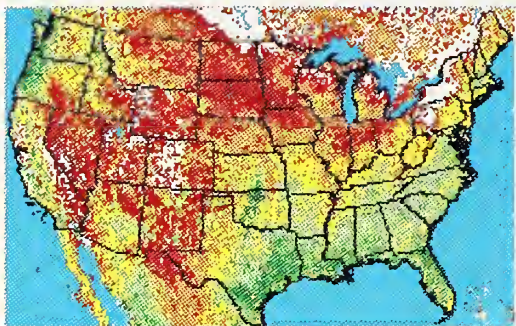
March 26, 1992
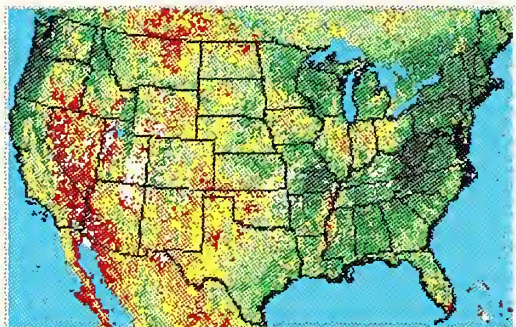
June 4, 1992
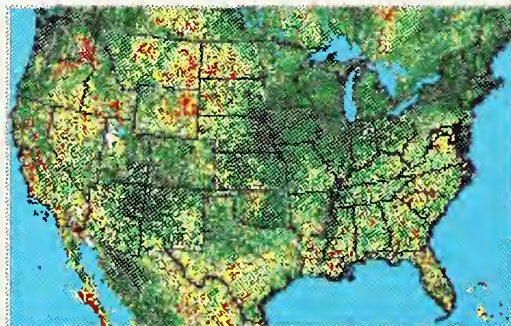
August 27, 1992

October 10, 1992
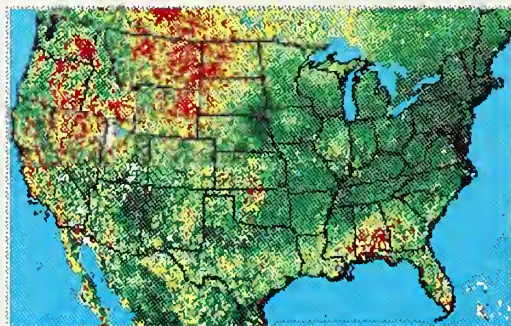
RELATIVE GREENNESS

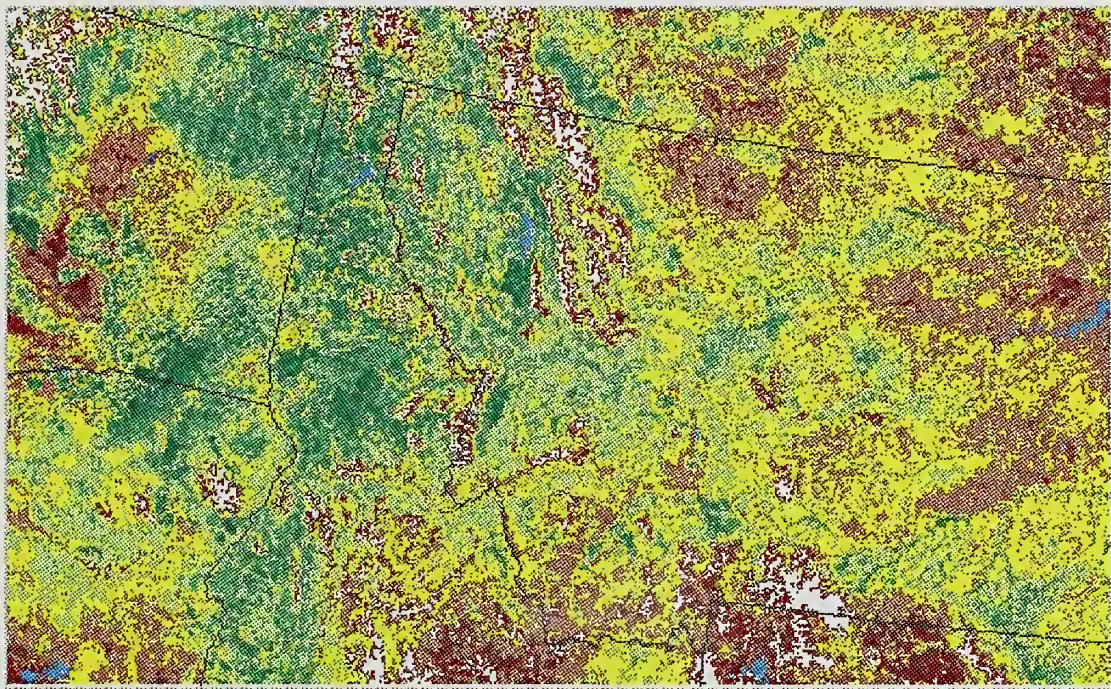March 26, 1992

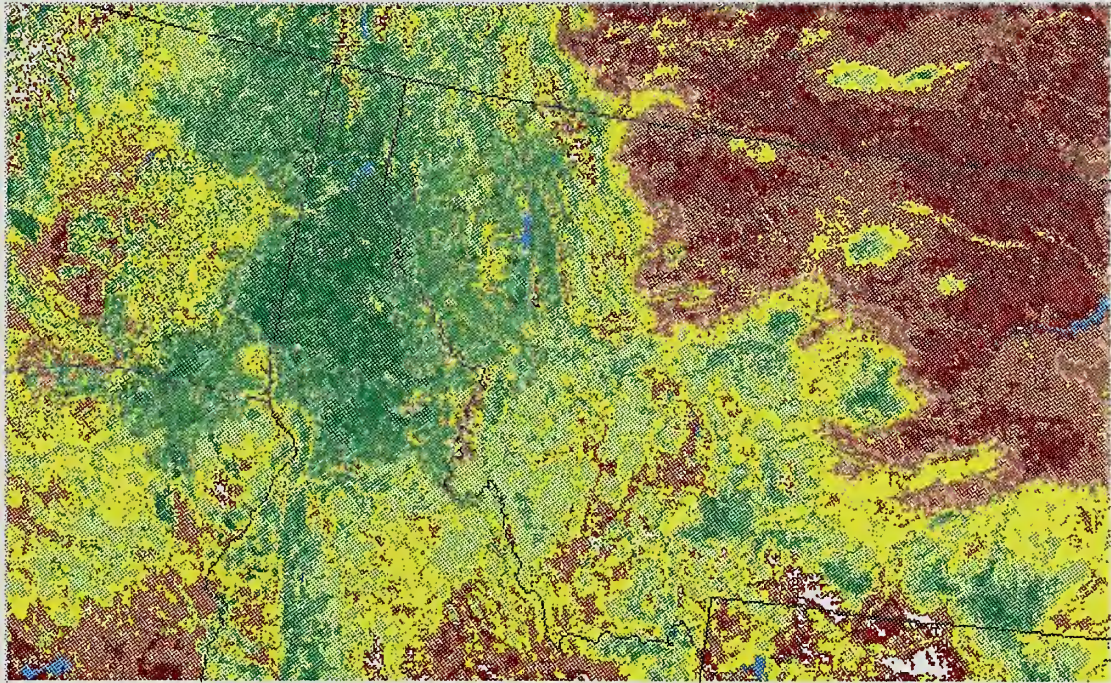June 4, 1992

August 27, 1992

October 10, 1992

Figure 5—Visual greenness maps portray vegetation greenness in comparison to a standard NDVI reference value of 0.66 as fully green, while the relative greenness maps portray vegetation greenness with respect to historical data recorded for each pixel.

8

May 30, 1991

May 28, 1992

Figure 6—Comparison of images at the end of May 1991 and 1992 shows much different patterns of snow cover and vegetation greenness in the Northern Rocky Mountain area.

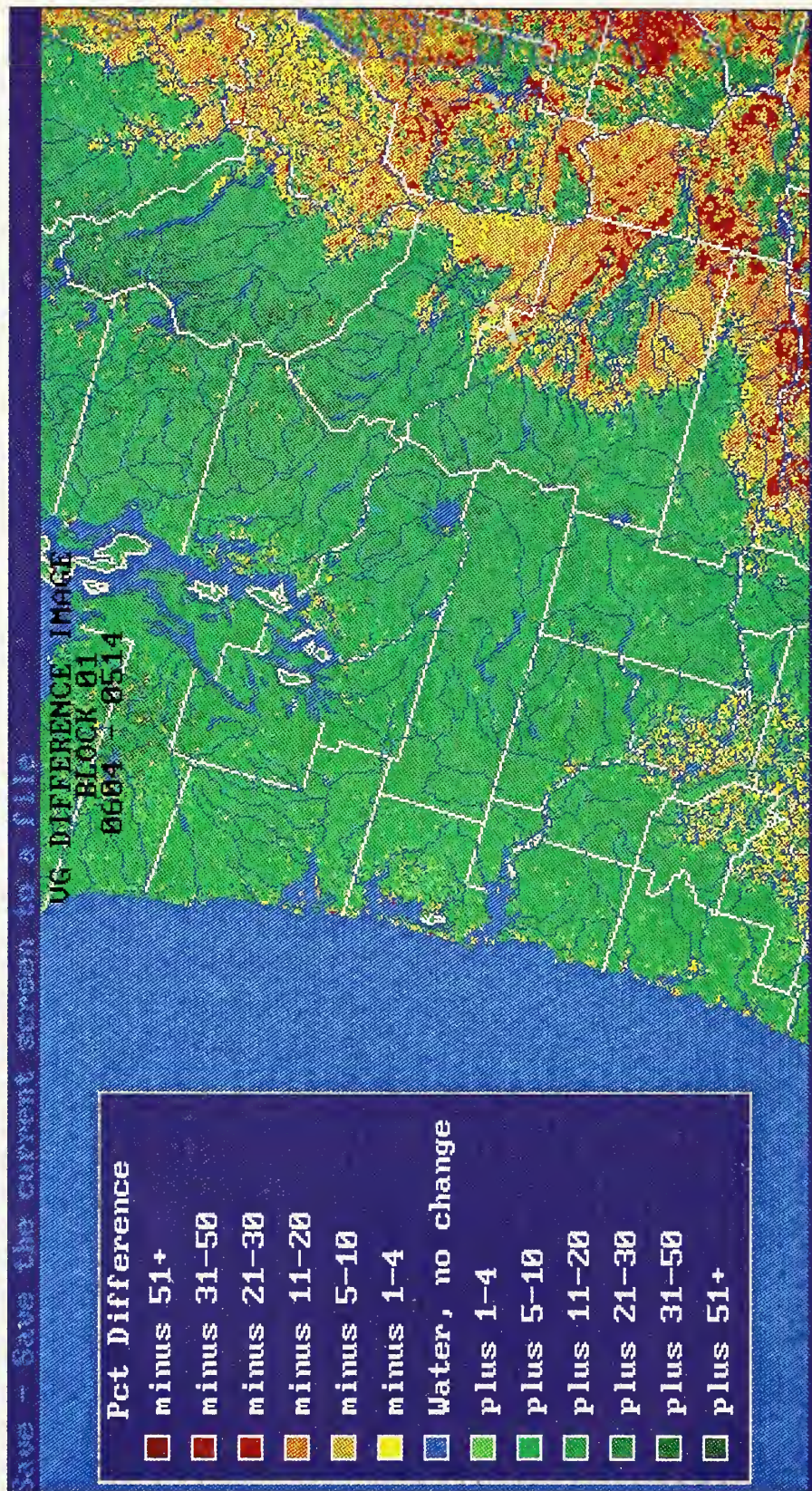**Figure 7**—A difference image created by subtracting visual greenness of May 14 from June 4, 1992, indicates extensive greenup during this period west of the Cascade Range in Washington, but considerable curing of vegetation east of the Cascades.

A high-speed data communications link and work station technology are necessary to access the full data set. But region, State, and district land managers can use personal computers to access data for just their area of interest at a reasonable cost in time and money.

Suggestions for use of this technology:

1. The 1988 NFDRS requires separate greenness factors for grasses and shrubs. The value of these factors ranges from 0, which represents cured vegetation, to 20, which indicates the vegetation is as green as it ever gets. While separate greenness factors cannot be derived from the greenness maps, you can divide relative greenness percentages by five to estimate a single greenness factor, then use your judgment to split it into separate greenness factors for grasses and shrubs.

2. You can assess where, when, and how extensively vegetation is curing or greening across your area of responsibility. This information could be useful to range managers who are trying to keep track of the range condition or fire managers who are trying to assess wildfire potential.

3. The extent, timing, and area coverage of snow can be assessed weekly. This information is useful in watershed management and tree planting programs.

4. Because fire is sensitive to the quantity of green vegetation, prescribed burning activities can benefit from weekly assessments of the extent and timing of vegetation greening and curing.

5. Forest pest managers are assessing the greenness maps to determine if they can time insect damage assessments through vegetative flushes portrayed by the greenness maps.

6. The timing and extent of drought can be assessed by comparing vegetation greenness during the current year with that of previous years.

SOFTWARE, HARDWARE, AND DATA ACCESS

Personal computer users can use a PC program (PCTGRN) to calculate greenness images from NDVI data and a second program named "Image Display and Analysis" (IDA) (Pfirman 1991) to display the images and to obtain quantitative data from them. The IDA program was developed with funding provided by three Federal government agencies. Thus the software is in the public domain. It is fully capable of more image analysis and display than was presented here, and is the program of choice for displaying greenness data. Batch files have been prepared to ease your use of this program for displaying images. An IDA self-study guide on disk has also been prepared for those who wish to use the program in more depth. This guide can be obtained by writing to Intermountain Research Station, Attn: Publications Distribution, 324 25th Street, Ogden, UT 84401, or phoning (801)625-5437. Ask for "IDA Self-Study Guide."

The Weather Information Management System (WIMS) will host NDVI-related software and data discussed in this report. WIMS is installed at the National Computer Center, U.S. Department of Agriculture, Kansas City (NCC-KC). Questions relating to signing on to WIMS or to obtaining the data or programs described here can be addressed to the National Fire Weather Support Center at (406) 329-4950 (commercial and FTS), or commercial 1-800-253-5559, or at NFW:R01D for Data General users.

To display the greenness maps, you must obtain software and data files from the NCC-KC. Because an NDVI data file for the entire United States is large (13 megabytes), the country has been divided into 42 blocks. Refer to figure 8 to decide which blocks are of interest. It takes about 8 minutes to retrieve NDVI data for each block, if you are using a 9600 baud modem.

Two files that provide instructions on what files to retrieve and how to retrieve them are maintained on WIMS: (1) NDSTART, which contains information and instructions on obtaining basic programs and data files as well as how to install these files on your PC; and (2) NEWIMAGE, which contains an announcement of NDVI images that are currently available. To access these files, sign on to WIMS and enter the word "docs." This will take you to the online documentation section of the shared directory and display a number of document file names. NDSTART and NEWIMAGE will be among the names listed. Print out the NDSTART instruction file. Refer to WIMS documentation or use the online help key if you need help in printing this file on your local printer.

The following hardware is necessary to retrieve and display, on your PC, images similar to those presented here:

1. A 286-, 386-, or 486-based PC. A mathematics coprocessor is not necessary, but it greatly improves image processing speed.

2. An EGA or VGA color monitor.

3. A 9600-baud modem if you plan to retrieve images directly to your PC. These modems can be obtained for about $200.

4. A data retrieval program named SIMPC, for retrieving NDVI images from the NCC-KC. This program can be ordered from NCC-KC for $169. When ordering, specify that the program is for use with WIMS to ensure that it comes properly configured.

5. A screen capture program. An example is PIZAZZ. Such software is advertised in computer software catalogs for about $100.
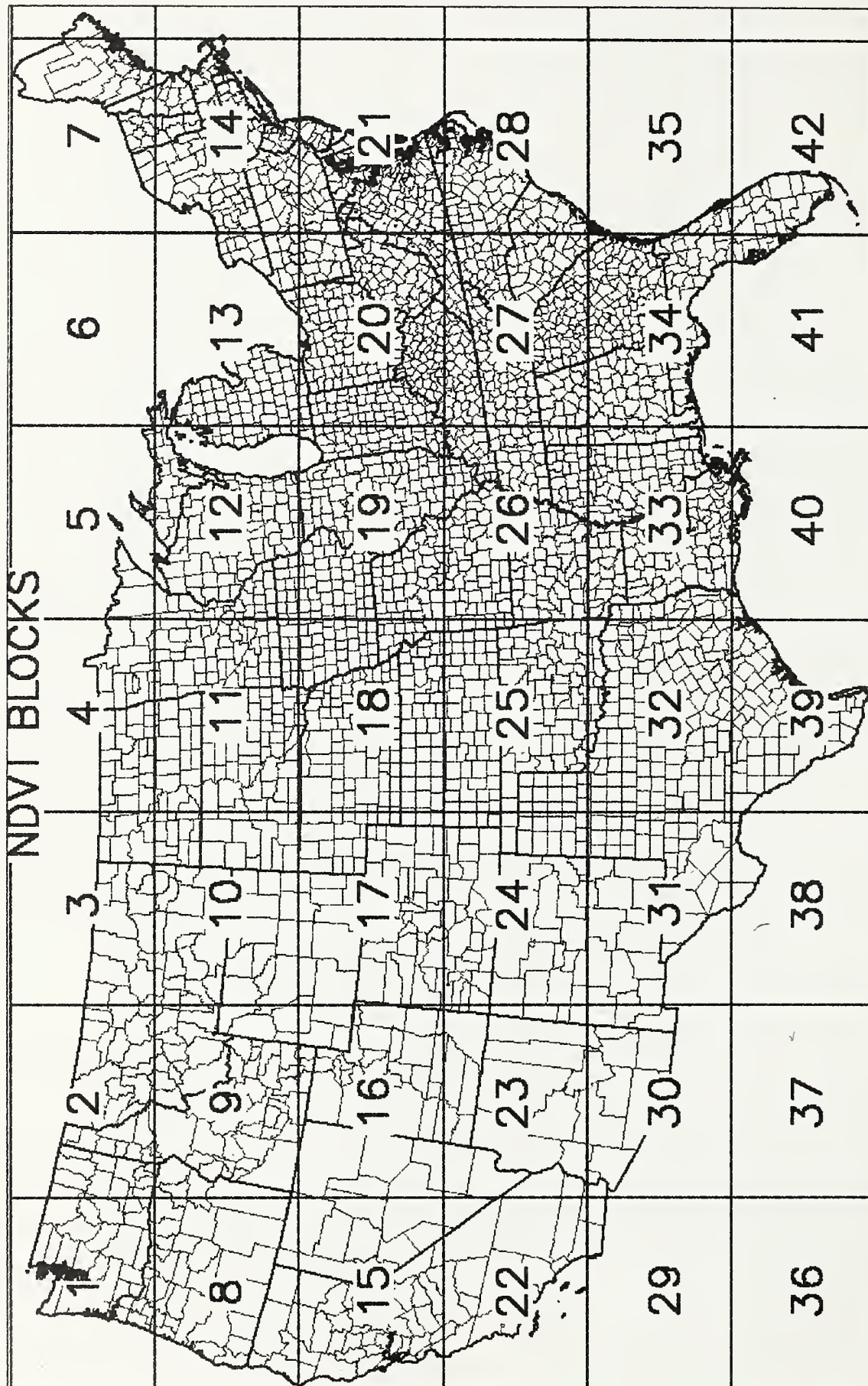
Figure 8—Updated NDVI data can be obtained weekly for any of the 42 blocks into which the United States has been divided. The file size for each block is 307712 bytes.

6. A color inkjet printer, supported by your specific screen capture software, to make hard copies of screen images. Acceptable printers are available for about $600.

If you don't want to make color hard copies of the images, the color printer and the screen capture program are not necessary.

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Vegetation greenness can be monitored at 1-km resolution for the conterminous United
States through data obtained from the Advanced Very High Resolution Radiometer on the
NOAA-11 weather satellites. The data are used to calculate biweekly composites of the
Normalized Difference Vegetation Index. The resulting composite images are updated
weekly and made available to land managers who then calculate and display two meas-
ures of percentage vegetation greenness. The images provide a useful method of
monitoring the condition of vegetation for fire or range management or other land manage-
ment functions.

**INTERMOUNTAIN
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The Intermountain Research Station provides scientific knowledge and tech-
nology to improve management, protection, and use of the forests and range-
lands of the Intermountain West. Research is designed to meet the needs of
National Forest managers, Federal and State agencies, industry, academic insti-
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made available through publications, symposia, workshops, training sessions,
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The Intermountain Research Station territory includes Montana, Idaho, Utah,
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area, about 231 million acres, are classified as forest or rangeland. They include
grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for
forest industries, minerals and fossil fuels for energy and industrial development,
water for domestic and industrial consumption, forage for livestock and wildlife,
and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have
missions that are national or international in scope.